LITERATURE REVIEW AND ASSESSMENT OF GEOLOGIC LOGS TO DETERMINE THE EXTENT OF A DENSE LIMESTONE LAYER IN THE UPPER PORTION OF THE BISCAYNE AQUIFER IN THE PENNSUCO WETLANDS, MIAMI-DADE COUNTY, FLORIDA

Technical Publication HESM-1

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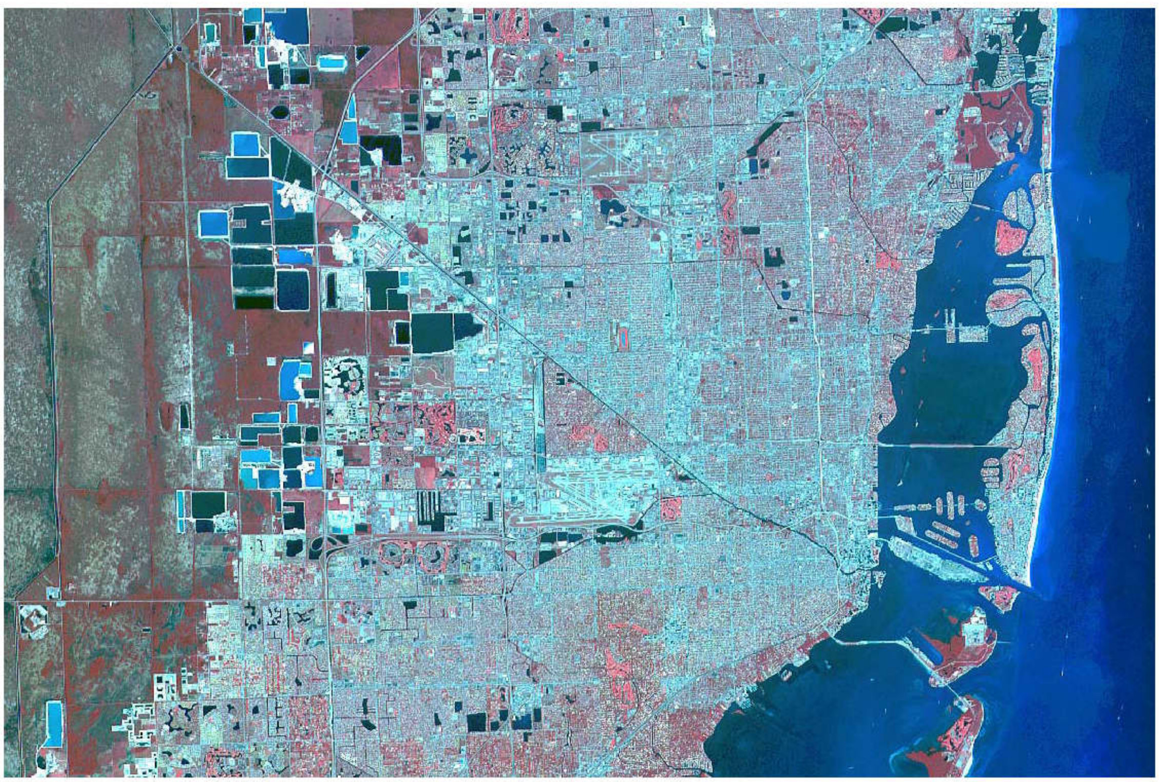

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LIST OF ABBREVIATIONS AND ACRONYMS

bls	below land surface
C-#	Canal number
DLBS	Dade Lake Belt Study
DERM	Department of Environmental Resource Management
District	South Florida Water Management District
gpd	gallons per day
L-#	Levee number
msl	mean sea level
mgd	million gallons per day
SAS	Surficial Aquifer System
SFWMD	South Florida Water Management District
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey
WCA-3B	Water Conservation Area 3B

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INTRODUCTION

The objective of this work is to describe the extent and continuity of a shallow, dense limestone layer in the upper portion of the Biscayne Aquifer in the area of the Pennsuco Wetlands and part of Water Conservation Area 3B (WCA-3B) to the west. The information will be used to develop a model layer representing this stratum for simulation of surface water and groundwater interactions.

The Pennsuco Wetlands is an area about 2 miles wide and 10 miles long, on the east side of Levee 30 in the northwest Miami-Dade County limestone mining area (**Figure 1**). To the west of Levee 30 is WCA-3B. The study area includes the Pennsuco Wetlands, as well as the eastern portion of WCA-3B, north to Canal 11 in Broward County and south to approximately 8 miles beyond Tamiami Trail. The eastward limit of the study area is the western edge of the mining lakes in northwest Miami-Dade County. The northwest boundary of the study area is Levee 67C. The entire study area is about 22 miles north to south and about 7 miles east to west.

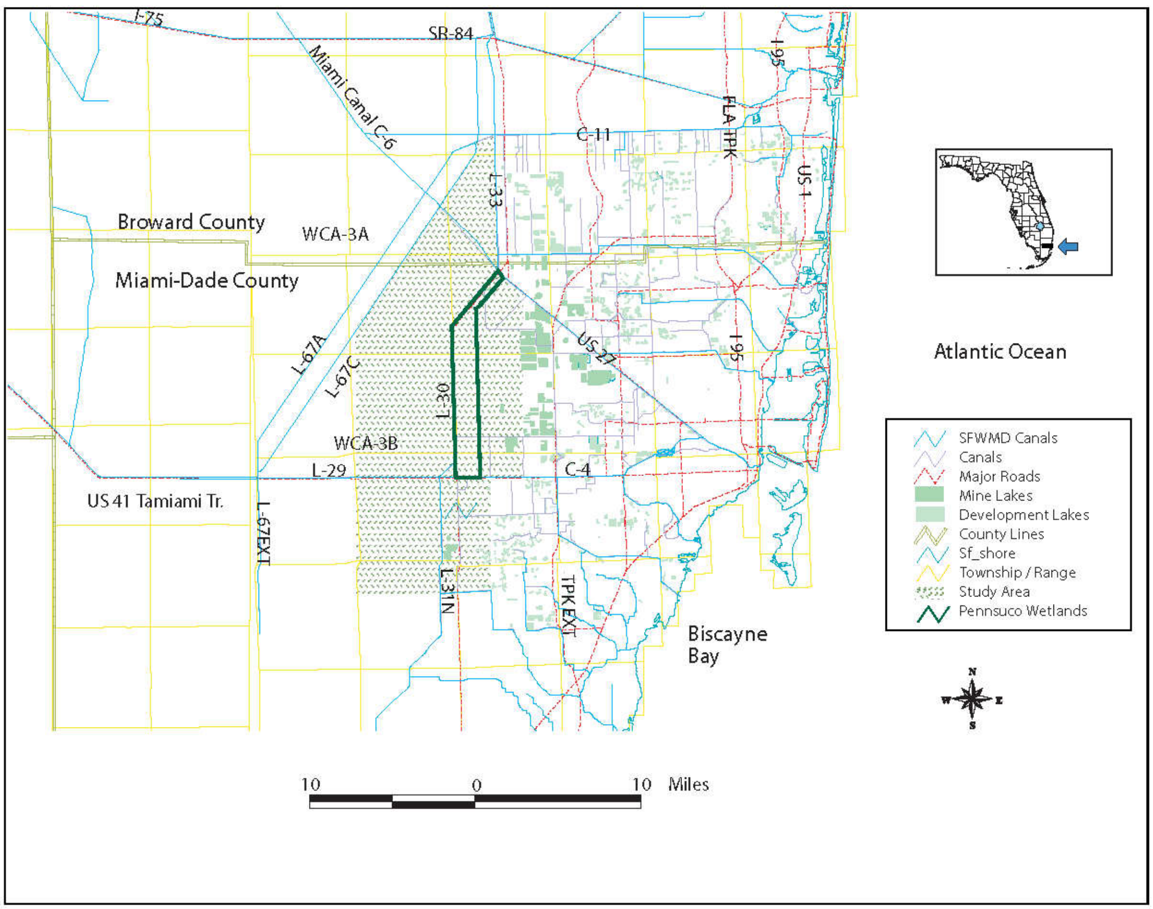

Figure 1. Location of the Study Area

STRATIGRAPHY OF THE STUDY AREA

In the study area, the typical undisturbed stratigraphic sequence from the land surface begins with 1 to 3 feet of peat or muck and lime mud (marl). The marl, known as the Lake Flirt Marl, is typically a soft, gray, calcareous mud of freshwater origin. The Lake Flirt Marl is practically impermeable (horizontal hydraulic conductivity < 0.1 feet/ day; <0.8 gpd/square foot) and in some instances is lithified to a dense limestone. In this area, it may occur in lenses or pockets overlying the irregular upper surface of the limestone below it, or as thin layers interfingering with the organic deposits.

Underlying the surficial sediments is the Miami Limestone (formerly referred to as the Miami Oolite), forming the upper portion of the Biscayne Aquifer. There are two facies of the Miami Limestone: an oolitic facies and a bryozoan facies. Although both facies are normally present, only the bryozoan facies is present in the study area. The Miami Limestone has alternating layers of harder and softer limestone and occasionally contains a layer of light gray, freshwater limestone, which is typically very dense and hard. The hydraulic conductivity of the Miami Limestone is low to moderate (horizontal hydraulic conductivity 0.1 to 100 feet/day; 0.8 to 748 gpd/square foot), except where voids and fractures are present.

The Fort Thompson Formation lies beneath the Miami Limestone and forms the more permeable portion of the Biscayne Aquifer. The Fort Thompson Formation consists of a thick sequence of mostly marine limestone with thin layers of brackish and freshwater limestone. At depths beyond 20 to 30 feet below the land surface, the marine limestones are very permeable (horizontal hydraulic conductivity >1,000 feet/day; >7,480 gpd/square foot), due to the presence of secondary-solution cavities.

Freshwater limestones often mark the top of the Fort Thompson Formation. However, as they sometimes occur in the Miami Limestone, the contact between the Miami Limestone and Fort Thompson Formation is placed at the base of the lowest oolitic limestone.

IDENTIFICATION OF THE DENSE LIMESTONE LAYER

In the early 1950’s, levee site investigations by United States Army Corps of Engineers (USACE) revealed a hard, dense, low-permeability limestone near the top of the Biscayne Aquifer from borings taken at the north end of Levee 30. This limestone occurs at approximately sea level near the contact of the Miami Limestone and the Fort Thompson Formation. The lower contact is irregular. The limestone has been called a solution breccia by several authors as it appears to have been formed from the accumulation of various limestone clasts packed and cemented within a very fine micritic (microcrystalline calcite) matrix. The dense nature of the limestone would indicate that hydraulic conductivity would fall in the very low to practically impermeable range (less than 0.1 feet/day (< 0.8 gpd/square foot)). Typical features include subaerial crusts, intraclasts, finely laminated features in some samples and iron oxide staining. Most core samples are limestone conglomerate, with a brecciated or mottled appearance. Colors vary from yellowish brown to reddish brown and yellowish orange to medium gray and brownish gray. Thickness is typically less than 1 to 3 feet, but may locally reach 5 feet where it may have filled holes in the uneven surface below. Where broken, the fracture is often conchoidal and angular, giving a cherty appearance. Quartz sand is often present.

The dense limestone layer that is the focus of this paper stands out not only because of its dense nature, but because of its unique appearance and hardness. However, this is not the only dense unit within the upper Biscayne Aquifer. Other dense layers are present, including several thin layers of gray freshwater limestone, which are quite hard. Freshwater limestones are especially common on the Okeechobee and Caloosahatchee depressions (Perkins 1979). They are known to occur in the basal portions of units beneath marine sediments, but are best preserved in the upper portions of units where they have become lithified through subaerial exposure. These upper freshwater units are commonly solution-riddled, bored or capped by laminated crusts. These brecciated laminated crust deposits were the main features used in identifying stratigraphic sequences.

The top several feet of the Fort Thompson Formation are denser relative to the highly permeable intervals comprising the bulk of the aquifer. The Miami Limestone, where open solution channels are not present, has a much lower permeability than the highly permeable zones in the Fort Thompson Formation.

Regionally, all of these dense layers at or near the upper surface of the Biscayne Aquifer behave collectively as a semiconfining unit. Also, on the surface, the low permeability peats, mucks and marls behave as a semiconfining layer.

The confining nature of these dense materials is the focus of this report which contains a literature review and assessment of geologic logs. The goal of this review and assessment is to correlate the lateral extent the low-permeability limestone near the top of the Biscayne Aquifer.

Correlating information from the USACE levee studies with other reports and data was a challenge due to several different factors:

1. Correlating these discrete units or beds even over short distances is difficult. The sediments are frequently lenticular and discontinuous and may grade from one lithologic type to another. They may have been altered by solutioning and redeposition. Within a given formation, different facies may exhibit variations in color, texture, fossil types, porosity, permeability and infilling.
2. There is an inherent problem of scale. Site-specific investigations and regional investigations have different goals and purposes and employ different techniques for sample description and analysis. It was difficult to correlate lithologic descriptions written by different geologists due to variations in format, style, purpose, scale and sampling interval. Difficulties also existed in the correlation of lithologies because of the differences in drill-

ing and coring techniques, which yielded samples of varying quantity and quality.

3. Although numerous boreholes were drilled by the USACE for levee investigations, it appears that the borings at the north end of Levee 30 were the only logs published. Only generalized cross-sections are available for most of the transects. More detailed lithologic logs from those investigations could help to improve the correlations with logs from other studies.

4. Observation of original USACE (1976) samples would be the best way to determine correlations. Unfortunately the original samples from the levee investigations were destroyed and are not available for examination. Examination of samples taken by the South Florida Water Management District (SFWMD or District) has produced important additional information on the appearance of the dense limestone layer (Switanek, 2001).

5. Another scale problem is encountered with permeability of layers denoted in cross-sections. Fish and Stewart (1991) explained in presenting their geologic cross-sections that rapid vertical changes in lithology and hydraulic conductivity could not be shown due to scale. Dense, less permeable layers separating several thin zones of high hydraulic conductivity were not represented. Rather, the higher range was shown, as this was more important in estimating lateral yields to wells penetrating the entire sequence. In other cases, authors represented the occurrence of several thin layers of low hydraulic conductivity as a single composite layer. In studies like these, which emphasize aquifer characteristics, the practice of lumping or omitting thin low-permeability zones made correlation difficult. The intent of this exercise was to determine whether the dense limestone layer is traceable over a large area for modeling applications, rather than to estimate hydraulic conductivities of layers.

BACKGROUND INFORMATION, REPORTS AND DATA

This section consists of excerpts from reports which yielded specific information on low permeability limestone layers in the Biscayne Aquifer and general characteristics of the shallow portions of the Biscayne Aquifer in Miami-Dade County (Klein and Sherwood 1961; Maurrasse 1976, United States Army Corps of Engineers 1976, 1951, 1952, 1953; Stallman 1956; Schroeder et al. 1958; Labowski 1988; Causaras 1987, 1985; Fish and Stewart 1991; Parker et al. 1955; Swain et al. 1991; Switanek 2001). The authors would like to note that several other studies were useful in formulating general background information (Cooke 1945; Evans 1987; Hoffmeister 1974; Hoffmeister et al. 1967; Merritt 1995; Perkins 1977; Pettijohn 1975).

KLEIN AND SHERWOOD, 1961

Klein and Sherwood in their 1961 publication titled, *Hydrologic Conditions in the Vicinity of Levee 30, Northern Dade County, Florida,* described thin layers of dense limestone occurring near the top of the Biscayne Aquifer. The authors indicated that these layers retard downward infiltration of ponded water. Two thin layers of this dense limestone near the north end of Levee 30 were described as follows:

> The area is blanketed by 3 to 5 feet of muck and marl that is underlain by a layer of solution-riddled Miami Oolite, a part of the Biscayne Aquifer, 1 to 2 feet thick. Figure 2 shows two thin layers of very hard, dense limestone at depths ranging from 0.5 foot above mean sea level (msl) to 3.0 feet below msl. In contrast to the high permeability of the underlying limestones, these thin layers appear to be relatively impermeable; and the vertical flow of water through them is many times less than the horizontal flow of water through the deeper, more permeable rocks. By effectively retarding the downward infiltration of water, the thin layers act as a confining unit that separates the ponded water in Water Conservation Area 3 from the water contained in the permeable limestone.
>
> Geologic information from test wells and shallow borings and reported information obtained in connection with canal excavations, indicate that the hard layers of dense limestone occur throughout most of Area B and in southern Dade County, and that they occur at about the same altitude. Each of the wells penetrated the impermeable layers approximately at sea level. Similar layers were noted in wells near the southern terminus of L-31 and in wells south of the Tamiami Canal and west of L-31. It is reasonable to assume that the relatively impermeable zones underlie much of Water Conservation Area 3 and that their confining characteristics are widespread. In places, the dense limestones probably contain openings through which rainfall can infiltrate rapidly; however, the overall continuity and the blanketing effect of these layers in general tend to retard infiltration. In the Miami area to the east, the Biscayne Aquifer thickens and contains much sand. The thin, dense limestones either thin and disappear or they occur deeper in the aquifer near the coast.

The authors did not publish the lithologic logs for the wells indicated in their figures (G-72, G-972, G-970, G-975, G-974 and G-973) and did not include any lithologic descriptions in the report.

MAURRASSE, 1976

Maurrasse's 1976 article titled, *Hydrogeologic Assessment of the Environmental Impacts of Quarry-Pit Lakes at the Maule Industries Pennsuco Site North Dade County, Florida,* documented a study focusing on hydrogeological impacts of quarry operations in the Pennsuco mining area. The article characterized the dense limestone indicated by Klein and Sherwood (1961). Maurrasse described a dense solution breccia or conglomeratic limestone often associated with laminated structure.

Lithologic descriptions from a borehole just west of Pit B in the Pennsuco mining area were similar to the descriptions from the 1951 USACE *Agricultural and Conservation Areas, Geology and Soils: Partial Definite Project Report*. Descending from land surface, Maurrasse described the lithology as follows:

> On the surface, the Everglades Peat is 1.5 to 3 feet thick, averaging around 2.5 feet. The muck is directly underlain by a thin veneer of the Miami Formation consisting of the bryozoan limestone facies. The Miami Limestone has a maximum thickness of about 2 feet in the study area. Below this, the following general limestone types occur within the Fort Thompson Formation:
>
> Solution breccia (immediately underneath the Miami Oolite)
>
> Upper coquina
>
> Freshwater limestone (in thin interbeds)
>
> Lower coquina (interbedded with the freshwater limestones)

The following excerpts are the complete descriptions for the two uppermost limestone layers, the Miami Limestone (bryozoan facies) and the solution breccia within the Fort Thompson Formation:

> Bryozoan Limestone
>
> Very pale orange (10YR 8/2), extremely heterogeneous in texture and well consolidated. Bryozoan colonies with typical knobby structure occupy about 60 to 80 percent of the rock by volume. Remaining constituents are rare molluscan shells, worm tubes, halimeda (calcareous algae) fragments, benthonic foraminifera and even, though rare, some coral fragments. The rock is extremely porous both in its micro and macrostructure. Its measured apparent porosity varies from 14 to 30 percent. The Bryozoan rocks show extensive solution effects particularly at the muck interface. However, both micro and macropores have not been filled by secondary calcite from recrystallization processes that are common in the underlying rocks.

> Solution Breccia
>
> The rock layer immediately underneath the Bryozoan facies is extremely varied in color, composition, texture and structure. It usually varies from medium gray (N5), brownish gray (5YR 7/1) with reddish brown shades to rust color at the contact zone with the overlying Bryozoan limestone. This limestone is very hard, dense and heterogenous in its structure. It is practically formed from the accumulation of various kinds of limestones packed and cemented within a very fine limy matrix. The most striking feature commonly associated with this rock is the laminated structure (stromatolitic structure) which is often parallel to the horizontal plane, but may also occur in between randomly oriented fragments. This rock has very little or no macroporosity and its apparent microporosity varies from 4 to about 11 percent. Its estimated thickness from the core sample is nearly 60 cm (2 feet), but from field observations along the spoil banks of the various quarry pits, the solution breccia may reach thicknesses of 150 cm (5 feet) and more. Lower contact is irregular.

The author makes reference to the report by Klein and Sherwood (1961) in the following excerpt:

> Practically, the area studied is underlain by a body of solution-riddled limestone so significantly heterogenous in its vertical make up to be considered as distinct zones in the aquifer. Klein and Sherwood (1961) also reported hard dense limestone layers of low permeability, interbedded in softer limestones of high permeability in the uppermost 1.2 meters (4 feet) of the aquifer in the vicinity of levee 30, which is west of the area studied. These authors did not give the lithologic description of these layers, but the stratigraphic situation indicated in their paper does suggest that they were referring to the solution breccia previously described. They also stressed the hydrologic importance of this dense zone in the vertical infiltration of water through the aquifer because of its occurrence throughout most of Area B in southern Dade County.

UNITED STATES ARMY CORPS OF ENGINEERS REPORTS

The United States Army Corps of Engineers (USACE) published project reports and design memoranda for construction and modification of the levee system in the region for the Central and Southern Florida Project. It was this work that Klein and Sherwood (1961) referred to when discussing the presence of the dense limestone layer. The following four cited USACE documents provide cross-sections and geological interpretations for the region of interest. A few boring logs were published, but most are believed to be unpublished.

USACE, 1976

The 1976 USACE *Coastal Areas South of St. Lucie Canal, Supplement 56 – Detail Design Memorandum* included geologic logs from the Levee 30 core borings drilled in 1951 along the borrow canal line at 2,000-foot intervals. Unconsolidated materials were sampled by hand auger or by rotary drilling. Below the unconsolidated zone, the limestones were cored with either single or double-tube core barrels. Unfortunately the samples were destroyed upon completion of the project.

Eleven boring logs from 1951 (Levee 30, Holes 31-41) were included in the report. The core locations spanned a distance of 15,000 feet in a southwest to northeast direction at the north end of what is now Levee 30. These core logs were studied to determine the presence of the dense hard limestone, as described by Klein and Sherwood (1961). This limestone was identified as a dense, varicolored, brecciated or conglomerated limestone underlying the Miami Limestone, based on Maurrasse's interpretation and descriptions in the 1951 and 1952 USACE reports. Using this interpretation as a guide, the zone was interpreted to be present in the core interval sections presented in **Table 1**.

It is possible that Klein and Sherwood (1961) were referring to thin, freshwater limestones. The freshwater limestones in these borings contained solution channels in all but three cases. For this reason, it was not concluded that these were the targeted dense limestone layers. Here, depth refers to the original land surface before construction of Levee 30.

In all other holes, the units immediately overlying and underlying the targeted zone had some form of solutioning or secondary porosity indicated. In the case of the oolite which overlies the target zone, the solution holes are typically filled with clay or marl, according to the author. As indicated by several authors, these infillings reduce (or eliminate) the effective secondary porosity.

The report also contains drilling logs from three boreholes completed at the site of Structure 337 in June 1973. The zone was interpreted to be present in the cores in the intervals shown in **Table 2**, based on the conglomeratic description and the absence of solution holes which were otherwise present in the overlying and underlying zones.

Table 1. Interpretation of Geologic Logs from Levee 30 Borings Showing the Presence of the Dense Limestone Layer (after USACE 1976)

Hole Number	Planar Coordinates X	Planar Coordinates Y	Depth, top to bottom (feet)	Elevation, top to bottom (feet)	Thickness of Dense Limestone Layer (feet)	Description
Levee 30 Hole 30	674470	573160	4.7 to 9.1	+1.4 to -3.0	4.4	Limestone, hard, dense, very slightly sandy, mottled, light gray, dark gray and buff, not very porous
Levee 30 Hole 31	675357	574248	4.5 to 5.0	+1.4 to +0.9	0.5	Limestone, slightly sandy, dense, hard, mottled, buff, gray and pink
Levee 30 Hole 32[a]	676230	575330	4.6 to 5.9	+1.3 to 0.0	1.3	Not apparent in this hole. The limestone which is likely to be the pick has solution holes and channels. Description was: Limestone, very slightly sandy, medium hard, with solution holes and channels, mottled buff, gray.
Levee 30 Hole 33	677115	576420	4.7 to 8.7	+1.0 to -3.0	4.0	Limestone, very slightly sandy, hard, non-porous, mottled buff and tan
Levee 30 Hole 34	678000	577508	5.0 to 7.3	+0.2 to -2.1	2.3	Limestone, hard, fairly dense, mottled buff and light gray
Levee 30 Hole 35	678882	578593	4.2 to 6.6	+1.3 to -1.1	2.4	Limestone, hard, dense, very slightly sandy, mottled buff and gray
Levee 30 Hole 36	679703	579602	4.2 to 5.5	+1.3 to 0.0	1.3	Limestone, hard, very slightly sandy, dense, mottled buff, gray, pink
Levee 30 Hole 37	680585	580689	5.2 to 6.2	+0.3 to -0.7	1.0	Limestone, hard, dense, very slightly sandy, mottled buff, light and dark gray
Levee 30 Hole 38	681467	581776	4.1 to 7.1	+1.5 to -1.5	3.0	Limestone, hard, dense, very slightly sandy, mottled buff, pink and gray
Levee 30 Hole 39	682349	582863	5.4 to 8.4	+0.2 to -2.8	3.0	Limestone, hard, dense, very slightly sandy, mottled light and dark gray and buff
	b	b	8.4 to 9.4	-2.8 to -3.8	1.0	Limestone, hard, dense, buff, freshwater
Levee 30 Hole 40	683232	583950	5.4 to 6.0	0.0 to -0.6	0.6	Limestone, hard, dense, mottled buff and gray
	b	b	6.0 to 6.8	-0.6 to -1.4	0.8	Limestone, hard, dense, buff, freshwater
Levee 30 Hole 41	683746	584889	4.0 to 5.0	+1.5 to +0.5	1.0	Limestone, very slightly sandy, hard, dense, mottled gray, pink, buff
	b	b	5.0 to 5.5	+0.5 to 0.0	0.5	Limestone, hard, dense, buff, freshwater

a. This unit is probably the same bed, but in this case exhibits secondary porosity as solution channels.

b. Dense freshwater limestone immediately underlies the target zone in most of the holes. In most cases, solution channels were noted in this particular bed of freshwater limestone. However, in three cases, holes 39, 40 and 41, no solution holes were indicated. For these cases, depths and descriptions for these particular freshwater limestones are included.

Table 2. Interpretation of Geologic Logs from Structure 337 Borings Showing the Presence of the Dense Limestone Layer (after USACE 1976)

Hole Number	Planar Coordinates[a]		Depth (top to bottom, feet)	Elevation (top to bottom, feet)	Thickness of Dense Limestone Layer (feet)	Description
	X	Y				
CB-S337-1	not given	not given	4.2 to 5.0	+0.8 to 0.0	0.8	Limestone, conglomeritic, hard, well cemented from +0.8 to 0.0
CB-S337-2	not given	not given	4.2 to 5.0	+0.8 to 0.0	0.8	Limestone, conglomeritic, well cemented, brown from +0.8 to 0.0
CB-S337-4	not given	not given	4.6 to 5.7	+0.9 to -0.2	1.1	Limestone, conglomeritic from +0.8 to 0.0

a. Coordinates are not given. The S-337 location is near Levee 30 Hole 41, at the confluence of the Miami Canal and Levee 30.

USACE, 1951

The 1951 USACE *Agricultural and Conservation Areas, Geology and Soils: Partial Definite Project Report* contains cross-sections compiled from borings along the proposed levee alignments. The sections are generalized and do not distinguish the specific dense limestone bed. The original logs of the borings were not included in the report. As indicated in the detailed boring descriptions published in the 1976 USACE document, the beds could not be distinguished or correlated on the cross-sections. Difficulty of correlation is explained by the following excerpt from page III-6:

> In the central and northern portion of the region the sediments grade from one lithologic type to another, are commonly lenticular, or may be altered by secondary processes of solution and redeposition, making it difficult to correlate beds even over short distances. Only lithologic differences, as observed in core studies, were used to determine formational breaks. No paleontological studies were made except for noting freshwater, brackish and marine faunal zones.

The following paragraphs are excerpts from the report, and contain references to a dense brecciated layer at the base of the Miami Limestone, as well as the freshwater limestone beds. The mention of the solution channels in the freshwater limestone supported the conclusion that the freshwater limestones were not the beds that Klein and Sherwood (1961) described.

Description of the principal aquifer, from page III-12:

> The Fort Thompson limestone is generally sandy, hard, porous, fossiliferous and riddled with interconnecting solution holes. The homogeneity of the formation is broken by several beds of hard, dense, buff to gray limestone of freshwater origin ranging in thickness from a few inches to several feet. Some of the denser beds can be traced over distances of several miles and others pinch out and reappear along a particular horizon. Solution channels occasionally penetrate those strata, permitting vertical movement of groundwater. The Miami Oolite is a hard fossiliferous oolitic limestone. Much is it is riddled with vertical solution holes which produce a much higher permeability vertically than horizontally. In many

> places dense limestone breccia or conglomerate, which is found at the base of the Miami Oolite, retards the downward movement of surface water to the underlying Fort Thompson limestone.

Description of the Miami Limestone, from page III-8:

> The Miami Oolite is equivalent in age to the upper portion of the Fort Thompson and Anastasia formations. It was deposited in the south and southeast as an oolitic limestone thickening from a feather edge along its northwestern border to a maximum of 8 feet along the southern end of levee 30 alignment. To the northeast the oolitic limestone becomes sandier and overlaps the Anastasia Formation, and to the north and northwest it becomes softer, grades to marl and overlaps the Fort Thompson Formation. In the southern areas, a dense limestone conglomerate is generally found at the base of the formation.

Description of the Fort Thompson Formation, from page III-7:

> In the southern part of Water Conservation Area 3, the Fort Thompson Formation consists of highly permeable, light-colored marine limestones and sandstones interbedded with several continuous zones of thin and relatively dense, gray to brown freshwater limestone. North of that area there is an abrupt facies change to much less permeable marine, brackish and freshwater limestones, shell marls and shelly and marly sands with variable degrees of induration. In many parts of the northern area the upper portion of the formation has been indurated to form a dense, hard cap-rock ranging from a few inches to several feet in thickness. The deposition of alternating freshwater, brackish and marine sediments is believed to coincide with fluctuations of sea level during the several glacial and interglacial stages of the Pleistocene epoch.

It should be noted that the cap rock mentioned here is described as occurring to the north of the study area for this publication, and is not indicated to extend southward into the USACE study area. It is possible that this cap rock is the northward expression of the hard, dense limestone of interest.

There is an interesting note about permeability of peat and muck soils (pages III-14 and 15).

> Laboratory permeability tests and field pumping tests indicate that seepage through peat soil is much greater vertically than horizontally. That can reasonably be attributed to the fibrous nature of the soil and its characteristic vertical channels. There is considerable evidence that the seepage movement in the Everglades is largely through the porous rock and sand beneath the peat.

Description and occurrence of marl, from page III-15:

> The marl soils are widely distributed under the organic soils and in places are consolidated into a hard limestone just under the peat. Usually, however, the marl is a soft, grayish-white, calcareous silt of freshwater origin. Other marls, with inclusions of sand, silt, clay and shell, appear within the area. The marl is not uniformly distributed; it often pinches out into the peat and muck. Generally it is quite impermeable, acting as a seal that retards movement of water.

USACE, 1952

This 1952 USACE *Test Levee Investigations: Partial Definite Project Report,* documented the construction and testing of a test levee located on the north side of Tamiami Canal, 940 feet east of the Krome Canal, or just east of where Levee 30 is today. An 890-foot east-west cross-section of the location clearly indicates a 1 to 3 foot layer defined in the legend as: limestone, hard, generally dense, conglomeratic appearance - Miami Oolite. It lies near the contact of the Miami Limestone and the Fort Thompson Formation, between 1.5 and 5 feet below mean sea level (msl). In the legend, the Miami Limestone and Fort Thompson Formation are indicated respectively as: “limestone, oolitic, hard, solution-riddled - Miami Oolite” and “limestone, hard, generally porous and with solution holes - Fort Thompson Formation”.

This cross-section was the only cross-section in the four USACE documents examined that defines the dense limestone layer. All other cross-sections are too small in scale to show this thin stratum.

USACE, 1953

This 1953 USACE *Agricultural and Conservation Areas, Design Memorandum, Permeability Investigation by Well-Pumping Tests: Partial Definite Project Report* contains information from 11 pumping tests performed in western Broward and Miami-Dade counties as part of the study for the proposed levees. Tests 1, 2, 3, 4 and 11 were located within the study area for this publication. Geologic cross-sections were produced from each site based on information obtained from drilling the test wells. The cross-sections are generalized and do not specifically depict a unique bed of hard, dense limestone. More detailed site information is not provided. Regional cross-sections across WCA-3 in southern Broward County are included in the USACE report. The sections are generalized, as necessary for scaling, and the unit cannot be located from the information provided.

STALLMAN, 1956

This Stallman study titled, *Preliminary Findings on Ground-Water Conditions Relative to Area B Flood-Control Plans, Miami, Florida,* published findings on groundwater conditions relative to Area B flood control plans in cooperation with the USACE. The following excerpt is from page 19, discusses seepage under Levee 30, Levee 31 and Levee 33:

> A highly permeable limestone formation underlies the entire area. Data collected by the U.S. Geological Survey indicate that the average transmissibility of this limestone in the western part of Area B is about 3 mgd/ft or about 4.6 ft^2/sec. The limestone is known to contain thin layers of comparatively impermeable rock that are believed to be of small aerial extent. However, the impermeable layers are probably extensive enough that the gross permeability of the limestone to vertical flow is materially less than its permeability to horizontal flow. The upper surface of the limestone is much less permeable than the deeper parts, according

> to data collected by the USACE. One field test indicated the vertical permeability of the upper 3 feet to be only 1 x 10^{-4} ft/sec. [57 gpd/ft^2]. The area tested formed a rectangle about 100 x 400 feet. It is not known specifically whether material having this low permeability blankets all of Area B.

SCHROEDER ET AL., 1958

The 1958 Schroeder et al. document titled, *Biscayne Aquifer of Dade and Broward Counties, Florida,* contains useful information on the characteristics of the Fort Thompson Formation and its contact with the Miami Limestone and described the dense, sandy limestone layer underlying the contact. The following excerpts are from pages 11-12.

> The Fort Thompson Formation in the Dade-Broward county area is predominantly light gray to cream, fossiliferous, marine, sandy limestone and calcareous sandstone, with a few thin beds of gray and tan fresh-water limestone. The entire section has been subjected to solution by groundwater, and the result is a cavity-riddled mass of permeable rock. Solution cavities are as much as several feet in diameter; some are filled or partially filled with fine and medium quartz sand. Some sand filling possibly occurred during flooding by Pleistocene seas. Loose sand such as this decreases the permeability of the aquifer, but if wells are heavily pumped much of the sand will be removed and a high permeability adjacent to a well will result.
>
> Cementation and redeposition of materials by groundwater movement are very much in evidence throughout the Fort Thompson Formation. Cementation of sand bodies by calcium carbonate has produced layers of hard, dense sandstone. Locally the cement is siliceous, producing a very hard quartzitic sandstone. An examination of limestone cores frequently shows secondary deposits of calcite crystals inside cavities or within concavities of marine shells. Fossils are preserved chiefly as molds and casts, rarely in their original form. Some cores of the Fort Thompson Formation show indications of bedding planes which provide zones of weakness along which groundwater solution takes place. Part of the Fort Thompson Formation is composed of very dense, hard nonfossiliferous limestone exhibiting little or no effect of groundwater action. In general, highly fossiliferous beds are markedly pitted with solution holes.

On page 14, Schroeder et al., continues the discussion of the Fort Thompson Formation and clearly describes the presence of a hard, dense, mottled sandy limestone near the contact of the Miami Limestone and the Fort Thompson Formation:

> The contact between the Fort Thompson Formation and the Miami Oolite, as observed in spoil banks along canals in the Everglades, is unconformable and is usually placed at the maximum depth at which oolites appear. The upper surface of the Fort Thompson is uneven and is characterized by solution pits and depressions and vertical solution holes. Oolitic material admixed with loose, sandy detritus from the Fort Thompson was deposited on this eroded surface and filled depressions to depths a few feet below the actual contact. These cavity fillings are easily discerned in core samples because the filling material is heterogeneous and shows a color contrast. A layer of very hard, dense, cream to gray, sandy limestone, which is peculiarly mottled or banded with brown and tan limestone, occurs in the Fort Thompson below the contact. In places the material

> appears to be a conglomerate containing weathered pebbles of the Fort Thompson Formation, but in at least some of these places the conglomerate is the result of irregular deposition of iron oxide in interstices of the Fort Thompson, along with differential cementation of those areas. The banding may denote an old eroded surface or may be the result of water table fluctuations.

Elsewhere in the document, the authors indicate lower permeability beds near the top of the Biscayne Aquifer that appear to act as a semiconfining unit, retarding downward infiltration. In the following excerpt, the authors attribute the lower permeability to the oolite and sand which form the top of the Biscayne Aquifer southeast of the study area for this SFWMD publication:

> At all the test sites, the Miami Oolite forms the upper part of the Biscayne Aquifer, and at most of them is underlain by a bed of sand. The permeability of the oolite and sand is lower than that of the underlying cavernous limestone of the Fort Thompson Formation and thus acts as a leaky roof during the pumping of a well, and the formation initially acts as an artesian aquifer (p. 39).
>
> The Miami Oolite or the sand separating the oolite from the limestone of the Fort Thompson Formation acts as a shallow semiconfining layer. These layers, where locally present, do not affect normal water-table conditions within the aquifer. However, they indicate that the components of the aquifer have variable hydrologic characteristics. They cause a difference in water levels immediately after pumping has started or stopped in two adjacent wells, one ending in the Miami Oolite or sand and one penetrating the deeper Fort Thompson Formation (p. 41).

The report delineated several zones of freshwater limestones. Specific information is presented on pages 14-20 regarding the origin, distribution and extent of these units.

LABOWSKI, 1988

The 1988 Labowski technical report titled, *Geology, Hydrology and Water Monitoring Program, Northwest Wellfield Protection Area,* included lithologic columns of 5 wells drilled adjacent to the Miami-Dade County Department of Environmental Resources Management (DERM) study area. The DERM study area extended from just inside the eastern edge of the study area for this SFWMD publication toward the east, near the turnpike. The near-surface deposits are described in the following excerpts. Emphasis should be placed on the freshwater limestone interbeds as well as the confining nature of the near-surface deposits.

> Near surface deposits (1 to 20 feet) consist of muck or peat, underlain by a thin layer of permeable oolitic and denser limestones (Miami Formation). Intercalated with the denser limestone are thin beds (less than 5 feet) of fine-grained limestone of freshwater origin.
>
> The freshwater limestones are generally taken as marking the top of the Fort Thompson Formation, which contains the principal water bearing zones of the Biscayne Aquifer in Miami-Dade County. However, as freshwater beds are sometimes seen interbedded with the oolitic limestone (e.g., G-3253A), the

> contact between the Miami Formation and Fort Thompson Formation is placed at the base of the lowest oolitic limestone.
>
> The first zone of high transmissivity is a fossiliferous limestone extending from approximately 20 to 30 feet below land surface.

No reference to a discrete dense, brecciated limestone is made by this author. The lithologic columns show the freshwater limestone layers (freshwater mudstone). No subdivisions of limestone are given to indicate the density, other than symbols for cavities or fossils. If a unique, dense brecciated layer exists in the Labowski study area, it cannot be distinguished from the information given.

CAUSARAS, 1987 AND 1985

Causaras completed detailed lithologic logs from 33 test wells drilled throughout Miami-Dade County. The findings were published in 1987 in a United States Geological Survey (USGS) Water Resources Investigations Report titled, *Geology of the Surficial Aquifer System (SAS), Dade County, Florida*. In 1985, an equivalent report was issued for Broward County. The geologic cross-sections published in this report were later used by Fish and Stewart (1991) in assigning hydraulic conductivity ranges to the same cross-sections. General formation descriptions and contact zone characteristics from Causaras (1987), sheet number 1, are quoted in the following excerpts:

> In some wells drilled in the Everglades and in coastal marshes, as much as 3 feet of the Lake Flirt Marl was penetrated filling in the troughs of the undulating erosion surface of the Miami Oolite. The Lake Flirt Marl is an upper Pleistocene to Holocene freshwater lake deposit, consisting of an admixture of silt, clay-size particles, micrite and freshwater snails that may contain an appreciable amount of peat and organic soil.
>
> The uppermost lithologic unit of the Surficial Aquifer System in most of Dade County consists of the oolitic and Bryozoan limestone facies of the Miami Oolite.
>
> The contact between the Miami Oolite and the Fort Thompson Formation is usually denoted by the presence of a subaerial crust containing intraclasts and stained by iron oxide.
>
> The Fort Thompson Formation consists of a series of alternating shallow marine, brackish water and freshwater limestone. The marine limestone is porous to very porous and pale orange to yellowish gray containing corals, bryozoans, abundant mollusks including Chione cancellata and the benthic foraminifer Archais angulatus. The species Archais sp. is commonly found on thalassia grass beds behind reefs and are abundant in patch reefs and outer reef tracts (Steinker, 1977). The marine limestone, in places, may grade to a moderately porous, brackish-water estuarine limestone containing both freshwater snails (Helisoma sp.) and marine clams. The freshwater limestone is gray, very well cemented, generally slightly to moderately porous and contains abundant snail remains including Helisoma sp. and Ameria sp. This freshwater limestone unit may either be in sharp contact with the marine limestone or occurs transitionally with the brackish-water limestone.

The report does not mention the dense limestone layer specifically, but the description of the contact zone between the Miami and the Fort Thompson was helpful in targeting its location in the lithologic descriptions. The wells in the vicinity of the study area are listed here from east to west, beginning at the north end:

- G-2316 and G-3294 along the Broward/Miami-Dade county line
- G-3296 (on Levee 67A), G-3297 (on Levee 30) and G-3298, across northern Miami-Dade County
- G-3302, G-3303, G-3304, G-3305 and G-3306, all on Levee 29, along Tamiami Trail
- G-3309, G-3310, G-3311 and G-3312 south of study area for this SFWMD publication

The logs from these wells were examined closely to determine the presence of the dense, brecciated limestone. It was difficult to correlate descriptions from previous studies with these logs. Sample description conventions and nomenclature differed significantly between studies. The scale of the investigations also differed. The work of Causaras's work was regional in nature; the purpose was to describe the geologic framework for the entire thickness of the SAS in Miami-Dade County. Most of Causaras's descriptions were for intervals of 2 to 6 feet or greater. Conversely, the work by the USACE was site-specific and focused on the shallow sediments; discrete intervals as thin as 0.4 feet were recorded.

Additionally, the Causaras report does not provide elevations with the logs; elevations had to be estimated from the cross-sections, based on sampled depths and estimated elevation of the land surface (usually levee top). The cross-sections are generalized representations of the formations, and individual facies and strata are not indicated.

Most of the recent borings were drilled through the levees as opposed to the USACE investigations of the early 1950s, before the existence of Levee 30. Typically, when the levees were constructed, unconsolidated sediments were removed (peat, muck, marl and sand). It is possible that the uppermost portions of the Miami Limestone were disturbed or altered in excavation and subsequent levee construction. Therefore, most well logs in the Causaras report begin with fill as the uppermost layer, then proceed directly into limestone. The 2.5 to 3 feet of peat, muck and marls, which were described in pre-levee USACE reports are largely missing, replaced with fill.

Nevertheless, the existence of the brecciated, dense limestone layer was confirmed in 11 (possibly 12) of the 14 wells in and around this area. **Table 3** indicates the results of the findings.

A map of well locations is included on **Figure 2** and the presence or absence of the brecciated, dense limestone layer is indicated in the map on **Figure 3**.

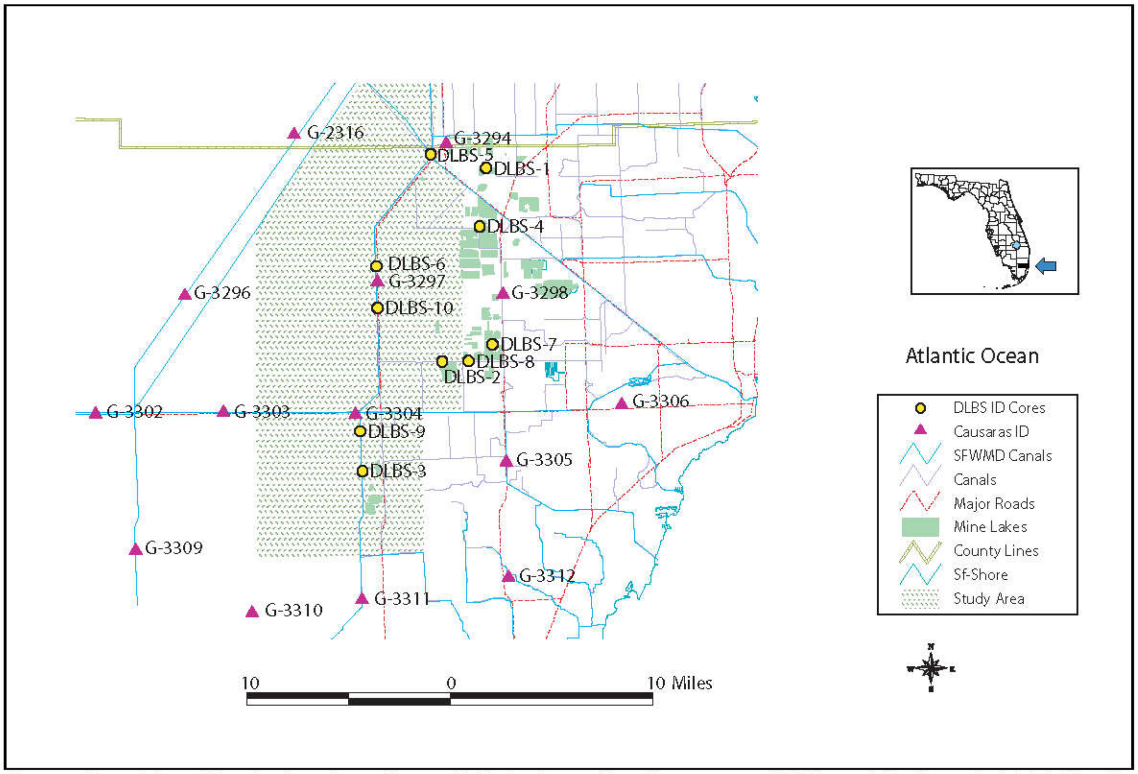

Figure 2. Map Displaying Location of Wells from the Causaras 1987 and Switanek 2001 Studies

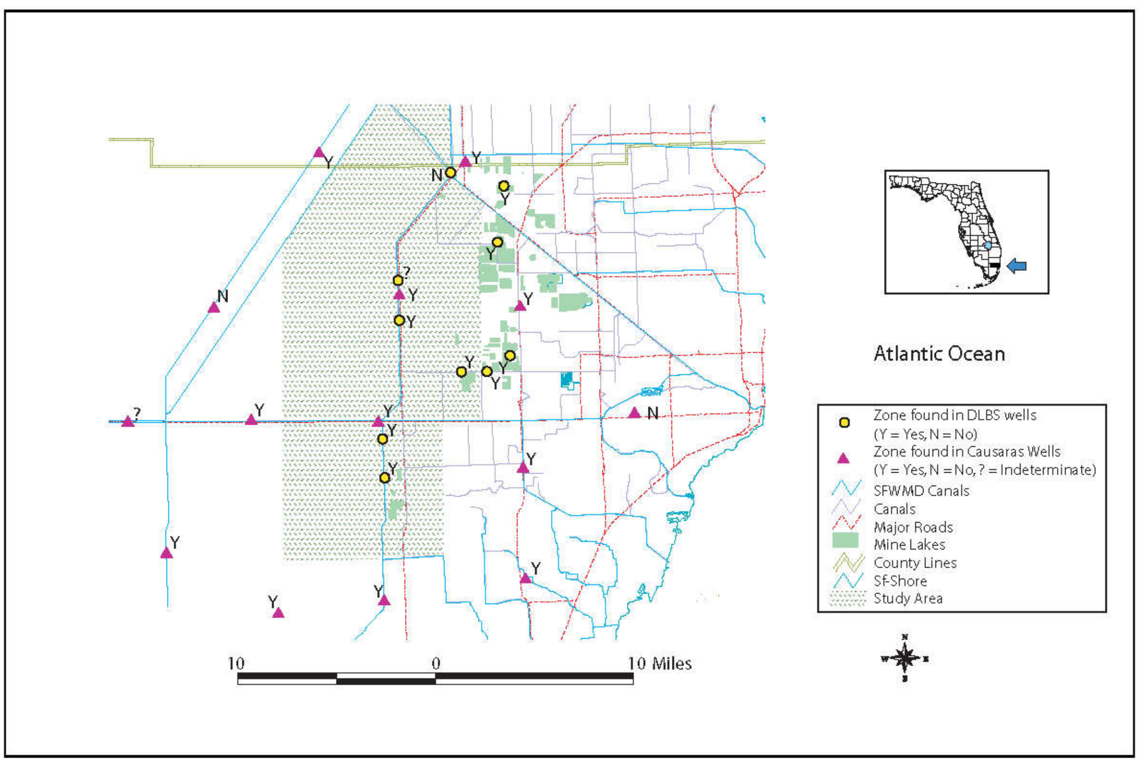

Figure 3. Map Indicating the Absence of the Dense Brecciated Limestone Layer in the Borings of Causaras 1987 and Switanek 2001 Studies

Table 3. Existence of the Brecciated, Dense Limestone Layer in Wells in and around the Study Area (as Interpreted from Causaras 1984)

Borehole ID	Location		Zone Present?	Depth (feet)		Estimated Elevation (feet msl)		Thickness of Zone (feet)
	Latitude	Longitude		Top	Bottom	Top	Bottom	
G-2316	255732	803256	Yes	16	19	-5	-8	3
G-3294	255707	802548	Yes	8	10	0	-2	2
G-3296	255043	803805	No	-	-	-	-	-
G-3297	255116	802903	Yes	10	12	0	-2	2
G-3298	255043	802310	Yes	10	14	-2	-6	4
G-3302	254542	804217	Maybe	13	14	-3	-4	1
G-3303	254545	803617	Yes	12	14	-1	-3	2
G-3304	254539	803006	Yes	10	14	2	-2	4
G-3305	254336	802303	Yes	10	12	2	-4	2
G-3306	254600	801737	No	-	-	-	-	-
G-3309	253954	804025	Yes	10	15	-2	-7	5
G-3310	253714	803459	Yes	18	20	-9	-11	2
G-3311	253746	802950	Yes	16	18	-2	-4	2
G-3312	253842	802258	Yes	8	10	6	4	2

Some indicators used to locate the targeted dense limestone from the lithologic descriptions included color variations of oranges, reddish browns and yellowish browns, well cemented texture, very-fine grain size, micritic matrix, brecciated or mottled texture, cherty fracture, presence of intraclasts and ferrous staining or other indications of subaerial exposure. Quartz sand was often present. Vugs were often present, but not likely to be connected.

FISH AND STEWART, 1991

Fish and Stewart conducted a USGS regional aquifer study in southeastern Florida titled, *Hydrogeology of the Surficial Aquifer System, Dade County, Florida*. To produce the plates in the report, original cross-sections from Causaras (1987) were reproduced and color overlays representing hydraulic conductivities were added. In the report, the Biscayne Aquifer is defined as follows:

> The Biscayne Aquifer, as used in this report, is defined as that part of the Surficial Aquifer System in southeastern Florida composed of (from land surface downward) the Pamlico Sand, Miami Oolite, Anastasia Formation, Key Largo Limestone and Fort Thompson Formation (all of Pleistocene age) and contiguous, highly permeable beds of the Tamiami Formation of Pliocene and late Miocene age where at least 10 ft of the section is very highly permeable (a horizontal conductivity of about 1,000 ft/d or more. (p.12).

The stratigraphy of the aquifer, beginning from the land surface, is described in the following excerpts:

> A generalized western Dade County hydrogeologic section (fig. 6c) begins in the northwestern area with a few feet of peat, muck and lime mud. At most drill sites, some or all of the sediments have been replaced with road or levee fill. Although no tests were performed in the organic deposits (peat and muck) for this investigation, Parker and others (1955, p. 109) indicate a relatively low permeability for these sediments. The lime mud layers, referred to as the Lake Flirt Marl (Holocene age), lie between the organic deposits and the rock floor to the Everglades or as thin layers intercalated with the organic deposits. These marl layers are unconsolidated to relatively indurated and are relatively impermeable, thereby retarding movement of water downward to, or upward from, more permeable layers below. These marls are absent or very thin in west-central Dade County, but lime mud is present in the lower Everglades and coastal marshes of southwestern Dade County. (page 30).
>
> The Miami Oolite forms the bedrock that underlies the Everglades over all of western Miami-Dade County, except the northwestern-most corner where it does not occur. In northwestern Miami-Dade County, the Miami Oolite may be either well cemented and very hard throughout its thickness, or have alternating layers of harder and softer limestone. The hydraulic conductivity of the Miami Oolite in the area is low to moderate, depending upon the presence of soft layers that have minor development of secondary-solution porosity. To the south and east, hydraulic conductivity increases as secondary porosity becomes better developed (pls. 6-9 and fig. 10a). Pumping of several wells open only to the Miami Oolite indicates that large yields can be obtained from this formation in some areas. However, test drilling also indicates that the cavities in many areas are at least partly clogged with lime mud and sand, thereby reducing the average hydraulic conductivity to much less than the underlying limestone. In general, the Miami Oolite does not appear to have as well developed a network of open cavities as the Fort Thompson Formation.

Fish and Stewart make general reference to hard, dense limestone layers on page 30 (excerpt below). Most of the limestone at or near the surface is denser than the underlying, highly permeable marine limestones.

> Marly limestone or hard, dense limestone layers with low hydraulic conductivity are predominant at or near the top of the Fort Thompson Formation in northwestern Miami-Dade County. The marine limestones of the Fort Thompson Formation generally are riddled with secondary-solution cavities and are very highly permeable (fig.10b). The cavities generally are 2 inches or less across but are so abundant that the limestone resembles a sponge, making collection of representative samples difficult. Interbedded with the marine limestones are much more dense, less permeable, freshwater limestones. Tests conducted during this investigation (table 5) and other studies (tables 3 and 4) indicate the average hydraulic conductivity of the Fort Thompson Formation over most of the area is tens of thousands of feet per day, possibly exceeding an average of 40,000 feet/ day.

The authors present ranges of horizontal hydraulic conductivity of sediments in the SAS (**Table 4**).

Table 4. Ranges of Horizontal Hydraulic Conductivity in the Surficial Aquifer System (Fish and Stewart 1991)

Qualitative Description	Horizontal Hydraulic Conductivity	
	Range (feet/day)	Range (gpd/square feet)
Very high	>1,000	7,480
High	100-1,000	748 - 7,480
Moderate	10-100	75 - 748
Low	0.1-10	0.8 - 75
Very low to practically impermeable	<0.1	<0.8

It should be noted that different facies of the Miami Limestone and of the Fort Thompson Formation occupy both ends of the conductivity spectrum. For example, portions of the Miami Limestone described as dense, hard oolitic limestone with no apparent solution cavities or fractures are included in the category of very low-to-practically impermeable, yet in other areas its hydraulic conductivity is very high, especially where open solution holes exist.

Similarly, the facies of the Fort Thompson Formation described as solution-riddle limestone, commonly shelly or sandy, is in the very high range, while the Fort Thompson facies described as very dense, hard limestone with no apparent solution cavities or fractures lies in the very low-to-practically impermeable range. Other facies of the Fort Thompson Formation may occupy the high or low ranges. The high range includes limestone or calcareous sandstone interbedded with sand or with sand partially filling cavities. The low range includes dense, hard limestone with very small cavities or channels and also approximately equal mixtures of sand, shell fragments and lime mud.

The hydraulic conductivity values cited in the Fish and Stewart (1991) report were gathered from the following: hydraulic data and municipal well data, flow rates obtained from test hole drilling, hydrologic inferences from inspection of geologic samples, published values of hydraulic conductivity as related to grain size and sorting for clastic sediments and sandstone, grain size description and sample sieve analyses.

The hydraulic characteristics of the Biscayne Aquifer are discussed on page 12:

> The hydraulic behavior of the Biscayne Aquifer may also cause confusion. Parker (1951) stated that the Biscayne Aquifer is unconfined. Throughout the area (except near well fields or margins of water conservation areas), water levels at depth are almost identical to local water-table elevations. Water in the Biscayne Aquifer is unconfined in that the potential distribution (as indicated by water levels in tightly cased wells) is closely related to the water table or to surface water bodies. As a result of considerable stratification and local permeability variations of the aquifer, water-level responses to aquifer tests of highly permeable zones overlain by much less permeable sands may exhibit semiconfined behavior, particularly during early stages of pumping.

The distinctive characteristics of very thin beds and their relationship to the regional scale of aquifer hydraulic conductivity of the formations are described by the authors in assigning hydraulic conductivity values to the cross-sections compiled by Causaras:

> The sections (pls. 1-11) provide an indication of the horizontal hydraulic conductivity of the rocks or sediments. Rapid vertical changes in lithology and hydraulic conductivity could not be shown because of the scale of the sections. Where it appears that several thin zones of high or very high hydraulic conductivity are present but are separated by less-permeable sediments (for example, dense limestone), the higher range is shown. In such instances, the sections give a more accurate portrayal of the capability of the formation to permit lateral movement of water rather than vertical movement of water. Also, because of limitation of scale, the occurrence of several thin (a few inches to a few feet) layers of sediments that have low or very low hydraulic conductivity is represented as a composite single layer (page 27).

PARKER ET AL., 1955

The Parker et al. report titled, *Water Resources of Southeastern Florida, with Special Reference to the Geology and Groundwater of the Miami Area,* included several exploratory test wells in the region around the study area, and three within the study area itself. The lithologic logs were published with the report. An examination of the logs and cross-sections did not reveal the existence of a shallow, dense limestone layer in most of the wells. However, the layer does appear to have been recorded in one well, G-219, located in Broward County on the east boundary of the study area. In two other wells directly east of the study area (G-187 and G-218), it may be present below 15 to 18 feet below land surface (bls), although this is uncertain based on the wide sampling intervals and composite descriptions. Information for the selected wells is listed in **Table 5**. **Figure**

4 is a reproduction of Parker's well location map, where presence or absence of the dense brecciated layer in these wells is indicated on the map.

Table 5. Existence of the Brecciated, Dense Limestone Layer in Wells in and around the Study Area (as Interpreted from the Well Logs of Parker et al. 1955)

Well ID	Approximate Planar Coordinates X	Approximate Planar Coordinates Y	Land Surface Elevation[a] (feet)	Land Surface Elevation derived from Parker (feet)	Dense Limestone Layer Identified?	Depth (feet, bls)	Elevation (feet, msl)	Notes on Relative Location
G-101	718582	522221	5.63	4.9	No	-	-	East, by Tamiami Canal
G-187	704120	567784	3.46	7.6	Maybe	around 18	~10	East, by Miami Canal
G-188	unknown	unknown	-	8.9	No	-	-	In study area. On Tamiami Trail G-218
G-218	702378	547584	4.55	5.1	Maybe	below 20?	below -15	East, by Snapper Creek Canal
G-219	unknown	unknown	-	7.2	Yes	between 9-16?	between -2 and -9?	East border in Broward County
G-222	unknown	unknown	-	9.1	No	-	-	West on Tamiami Trail
G-223	unknown	unknown	-	11.5	No	-	-	West on Tamiami Trail
G-224	717759	543116	5.98	6.2	No	-	-	East by Miami Springs
G-225	678191	539401	5.20	~9	No	-	-	In area. Miami-Dade Broward Levee
G-551	698974	494061	8.24	8	No	-	-	Southeast, near North. Kendall Drive
G-552	690480	467269	9.05	9.0	No	-	-	Southeast, west of Perrine

a. Land surface elevations in SFWMD geographic information systems coverage differ from Parker's originals. This paper used Parker's land surface elevation to estimate depth and elevation of zone where present. Planar coordinates are also from SFWMD's coverage. Parker provided locations in section, township and range.

SWAIN ET AL., 1991

The 1991 Swain et al. study titled, *Description and Field Analysis of a Coupled Ground-Water/Surface-Water Flow Model (MODFLOW/BRANCH) with Modifications for Structures and Wetlands in Southern Dade County, Florida,* conducted a modeling study on a regional scale. The study area in southern Miami-Dade County extended from the Miami-Dade/Monroe border on the west, east to Biscayne Bay. The northern boundary extended about 2 miles north of the Tamiami Canal, overlapping the southern end of the study area for this SFWMD publication by approximately 10 miles. Therefore, references to lithology of the northern portion of the model area can be applied to the southern portion of the study area for this SFWMD publication.

The generalized shallow stratigraphy and hydraulic conductivity of the area are described in the following excerpt from page 7:

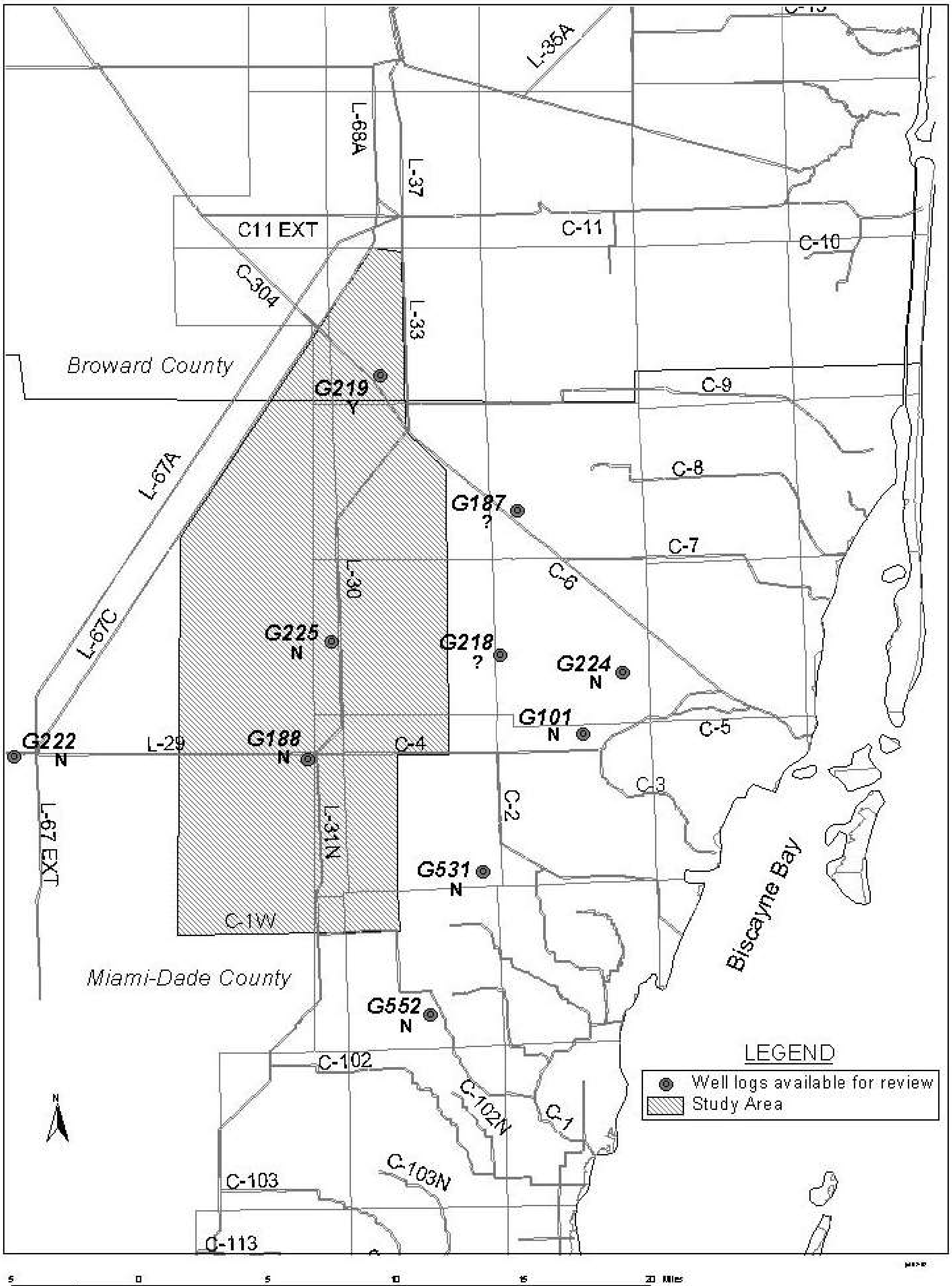

Figure 4. Presence or Absence of Dense Brecciated Limestone as Indicated in the Well Logs of Parker 1955 (Y= present; N= not present; ? undetermined)

> Surface deposits below the study area are primarily Miami Limestone (formerly called Miami Oolite) or a few feet of peat, muck, or lime mud overlying the Miami Limestone. The peat and muck are organic deposits generally present in the northwestern part of the study area or in the southern coastal areas. Lateral hydraulic conductivity data for the peat and muck are limited; however, the unit is considered to be of low permeability. Lime mud is mainly in the southwestern coastal parts of the study area and is considered to be relatively impermeable by Fish and Stewart (1991, p. 27). The peat, muck and lime mud sediments were assigned lateral hydraulic conductivities ranging from less than 0.1 to 100 ft/d by Fish and Stewart (1991).
>
> Miami Limestone either underlies the peat, muck and lime mud or is present at the surface in virtually all of the study area. Lateral hydraulic conductivity varies, depending on the degree of cementation and the development of secondary porosity. The limestone tends to be less permeable in the northwestern part of the study area where lateral hydraulic conductivity ranges from 0.1 to 10 ft/d and is more permeable in the eastern and southern parts where lateral hydraulic conductivity is greater than 1,000 ft/d (Fish and Stewart, 1991).

The tops and bottoms of the formations, as well as land surface elevations were obtained from the model developed by Merritt (1995) and from the study by Fish and Stewart (1991). The authors discretized the model into three layers as follows (pages 21-23):

> The model consists of one layer representing the wetlands and two layers representing the Biscayne Aquifer. Layer 1 represents the wetlands, from land surface to 15 ft above sea level. Layer 2 extends from land surface to the base of the Miami Limestone and includes the low-permeability peats and marls present in the northwestern and southern parts of the study area. Layer 3 includes the highly permeable sediments of the Fort Thompson Formation.

Hydraulic properties are described in these excerpts (p. 27, 30):

> Lateral hydraulic conductivities assigned to model layers (fig. 14) are modified from values assigned in the calibrated model of Merritt (1995). Vertical hydraulic conductivities are set at one-tenth the lateral hydraulic conductivity.
>
> For layer 2: Model cells representing areas where highly permeable Miami Limestone dominates the vertical column are assigned a lateral hydraulic conductivity of 30,000 ft/d. This value is based on aquifer-test analyses by Fish and Stewart (1991) and on the calibrated model of Merritt (1995). Model cells representing the northwestern part of the study area, where low permeability peats and marls dominate the relatively thin vertical column, are assigned a lateral hydraulic conductivity of 10 ft/d based solely on the calibrated model of Merritt (1995) because no test data are available for these deposits. In the north-central and south-western parts of the study area, the peats and marls are present but are thin relative to the Miami Limestone. Model cells representing these areas are assigned a lateral hydraulic conductivity of 20,000 ft/d based on work by Fish and Stewart (1991, p. 33).

SWITANEK, 2001

As part of a Dade Lake Belt Study (DLBS) conducted by Switanek titled, *Data Acquisition, Review and Analysis for the Lake Belt and Surrounding Areas, Miami-Dade County, Florida*, cores were obtained from ten boreholes drilled in the lake mining region in 1996. The boreholes were identified as DLBS-1 through DLBS-10. For this report, these cores were inspected twice to determine the presence or absence of the subject dense limestone. Initially, it was difficult to establish the existence of a single dense limestone zone, as there were several. However, once the characteristics of the dense brecciated limestone were established from the literature review, the samples were re-inspected, and the dense brecciated zone could easily be spotted in eight (possibly nine) of the ten cores. Photographs of the cores are included as **Figures 5** through **10**. The figures indicate the depths at which the dense limestone zone was found to be present in the cores. No photo is included for DLBS-5, which was the only borehole where the dense limestone was definitely not present.

Interestingly, DLBS-5 was the closest borehole to the north end of Levee 30 where the limestone had been originally identified in USACE borings, yet the DLBS-5 samples showed no trace of it. Additionally, the unit could not be positively confirmed in DLBS-6, the well located in the central segment of Levee 30.

Characteristics of this zone that make it unique from other dense zones include: dense, micritic texture, smooth conchoidal fracture, mottled appearance, color variations (orange, red, yellow, brown hues), wavy laminated features in some samples, location near the contact of Miami Limestone above (with ooids and bryozoans) and Fort Thompson Formation below (with various marine fossils and thin beds of freshwater limestone), subaerial crusts, intraclasts and iron oxide staining.

It should be emphasized that there are other dense strata throughout the upper portion of the Biscayne Aquifer, which perform the same hydrologic function of retarding downward infiltration. It is likely that this particular zone was recognized by its hardness and unique color and texture, as well as its density.

Well information for the SFWMD boreholes in the Miami-Dade Lake Belt study is presented in **Table 6**

The well locations indicating the presence or absence of the brecciated layer are included in **Figures 3** and **4** with Causaras's wells. Geophysical logs (gamma and neutron) were run in the holes, but do not appear to single out this dense layer in particular, as there are other dense zones with similar signatures.

The zone is present in boreholes DLBS-1 (**Figure 5**), DLBS-2 (**Figure 6**), DLBS-3 (**Figure 7**), DLBS-4 (**Figure 8**), DLBS-7 (**Figure 10**), DLBS-8 (**Figure 11**), DLBS-9 (**Figure 12**) and DLBS-10 (**Figure 13**). The zone may be present in borehole DLBS-6 (**Figure 9**). The zone is not present in borehole DLBS-5.

Table 6. Well Information for the Boreholes in the Miami-Dade Lake Belt Area (Switanek 2001)

Borehole ID	Planar Coordinates (NAD 1927)		Zone Present (Yes or No)	Depth (feet below land surface) where Zone is Present	Estimated Land Surface Elevation (feet msl)	Estimated Elevation of Zone (feet msl)	Thickness of Zone (feet)
	X	Y					
DLBS-1	697552	581888	Yes	5 to 8	7.00	2 to -1	3
DLBS-2	686284	532166	Yes	10 to 14	6.50	-3.5 to -7.5	4
DLBS-3	665810	503916	Yes	12 to 15	5.10	-6.9 to -9.9	3
DLBS-4	695900	566837	Yes	10 to 11	8.50	-1.5 to -2.5	1
DLBS-5	683310	585459	No	-	-	-	-
DLBS-6	669370	556629	Maybe	15 to 17	6.70	-8.3 to -10.3	2
DLBS-7	699236	536565	Yes	15 to 20	9.10	-5.9 to -10.9	5
DLBS-8	693048	532296	Yes	13 to 15	7.50	-5.5 to -7.5	2
DLBS-9	665208	514218	Yes	9 to 15	5.75	-3.25 to -9.25	6
DLBS-10	669668	545929	Yes	3 to 5	6.55	3.55 to 1.55	2

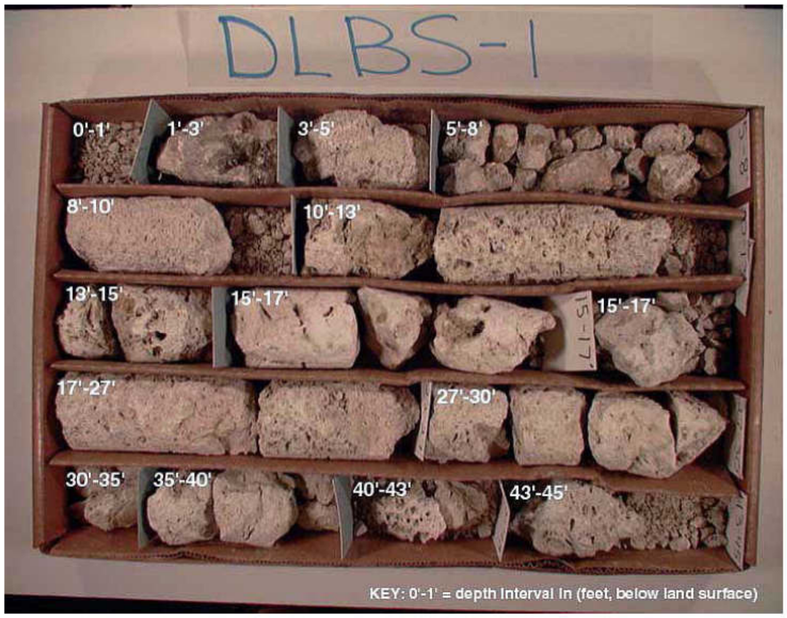

Figure 5. Photograph of DLBS-1 Core where Dense Limestone Zone was Identified at 5-8 feet bls

Figure 6. Photograph of DLBS-2 Core where Dense Limestone Zone was Identified at 10-14 feet bls

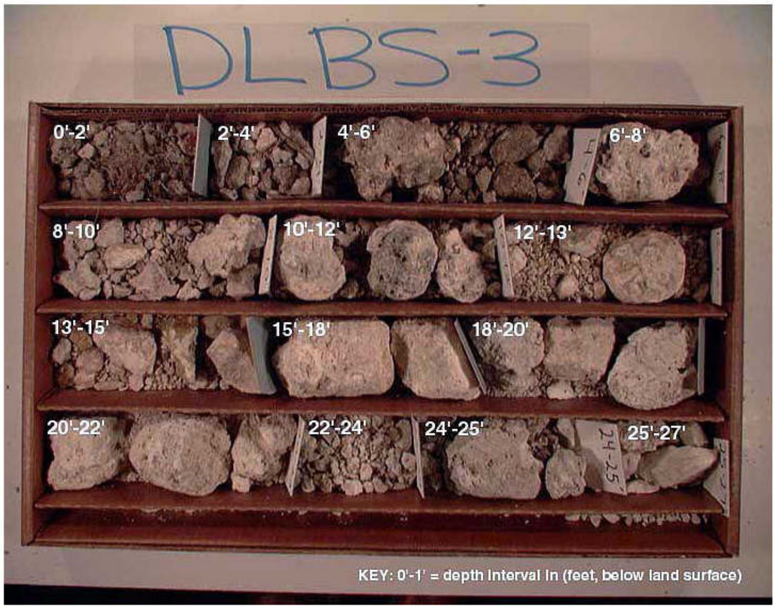

Figure 7. Photograph of DLBS-3 Core where Dense Limestone Zone was Identified at 12-15 feet bls

Figure 8. Photograph of DLBS-4 Core where Dense Limestone Zone was Identified at 10-11 feet bls

Figure 9. Photograph of DLBS-6 Core where Dense Limestone Zone was Possibly Identified at 15-17 feet bls

Figure 10. Photograph of DLBS-7 Core where Dense Limestone Zone was Identified at 15-20 feet bls

Figure 11. Photograph of DLBS-8 Core where Dense Limestone Zone was Identified at 13-15 feet bls

Figure 12. Photograph of DLBS-9 Core where Dense Limestone Zone was Identified at 9-15 feet bls

Figure 13. Photograph of DLBS-10 Core where Dense Limestone Zone was Identified at 3-5 feet bls

CONCLUSIONS

The hard, dense limestone conglomerate, occurring near the contact of the Miami Limestone and the Fort Thompson Formation in north-central Miami-Dade County was first identified in USACE borings along the site of Levee 30.

The dense limestone is traceable from many of the wells drilled in and around the study area by the USGS and the District. Of the ten borings drilled by the District, this dense limestone has been confirmed in eight.

In the logs of the USGS in this area (Causaras, 1986), the limestone was interpreted to be present in 11 (possibly 12) of 14 wells in or near the study area.

Logs and cross sections from other studies were examined, but were largely inconclusive based on the sample descriptions or wide sampling intervals. The logs from Parker et al. (1955) were better than most, although many of the sampling intervals were too wide to record such a thin zone. The unit was indicated in at least one, and possibly three of Parker's wells, all lying just east of the study area.

The layer is likely to be a discontinuous stratum infilling the irregular surface of the Fort Thompson Formation. Therefore, although it appears to be rather extensive over the study area, its occurrence at any single location is not certain. It does not appear to extend far to the east of the study area, due to the changing nature of the Fort Thompson Formation, which becomes very sandy to the east, nor does it appear to extend far to the west of the study area due to the disappearance of the Miami Limestone to the west.

Based on the information presented in this report, the following assumptions may be made:

- One or more confining units occur near the top of the Biscayne aquifer within the study area.
- These units are widespread, although perhaps not homogeneous, throughout the study area.
- For purposes of hydrologic modeling, it seems reasonable to model the effect of these units as a single low permeability layer throughout the study area.

For general purposes, it could be assumed that a two-foot thick layer of the dense limestone conglomerate exists throughout the study area near the contact of the Miami Limestone and the Fort Thompson Formation. However, the presence of other dense zones of marine and freshwater limestones in the upper portion of the Biscayne Aquifer should also be considered in the role of retarding downward infiltration of ponded surface water. Hydrostratigraphic units should be emphasized over lithostratigraphic units.

Regionally, the full sequence of dense materials comprising the top of the Biscayne Aquifer are known to be far less permeable than the bulk of the aquifer below. These units of lower permeability, combined with the peats, mucks, marls and sand overlying the bedrock work together to create a semiconfining, "leaky-roof" over the Biscayne Aquifer. This results in steady-state, long-term water levels in the aquifer that are the same as water table or surface water levels. However, the aquifer's water-levels in response to pumping may exhibit semiconfined behavior with increased drawdown, especially during early stages of pumping.

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